AFTERSHOCK ACCELEROGRAMS RECORDED ON A TEMPORARY ARRAY

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ABSTRACT

We recovered 52 timed analog accelerograms from 25 aftershocks of the 1979 Imperial Valley earthquake, between 3:33 p.m. P.d.t. October 16 and 5:43 a.m. October 31. The largest aftershock that we recorded (M_L=4.9) occurred at 4:16 p.m. October 16. This aftershock triggered eight accelerographs; preliminary estimates of epicentral distance range from 7 to 35 km. The data from this aftershock may be useful for study of both source and wave-propagation phenomena in the Imperial Valley.

INSTRUMENTATION

In the evening hours after the October 15, 1979, earthquake, a field crew was organized. Beginning early the next morning, they installed 10 accelerographs along the Imperial fault from north of Brawley, Calif., to the United States-Mexican border, with the object of recording aftershocks. The accelerographs (Kinemetrics model SMA-1) record three components of acceleration on 70-mm film, in the amplitude range of less than 0.01 to more than 1 g and in the frequency band 0 to about 25 Hz. These instruments were slated to be installed in the Los Angeles area as part of a network being established there by the University of Southern California and the California Division of Mines and Geology.

Each instrument has an internal clock (Kinemetrics TCG-1) that generates a time code to be recorded on the film. The clocks have a temperature-compensated crystal oscillator with a frequency stability of $\pm 3 \times 10^{-7}$ in the temperature range 0°-50°C; this stability implies a daily drift of less than 26 ms, provided the crystal frequency is set properly. The clocks tended to drift much less than this limit. Clocks were corrected in the laboratory before instrument deployment, at the time of installation on October 16, at most stations on October 17, and at the time the instruments were recovered on November 1 or 2. There is no reason to suspect an uncertainty of greater than 10 ms in the clock corrections interpolated to the occurrence times of aftershocks. Table 48 lists the locations, elevations, and orientations of the accelerograph installations (see fig. 296), as well as the sensor characteristics for each accelerometer.

RECOVERED DATA

One or more of the accelerographs were triggered by at least 25 aftershocks with preliminary local magnitudes estimated at from less than 3.0 to 4.9. Because of clock problems, the times of 5 of the 52 total triggerings are uncertain. Triggering times and S-wave arrival times for the remaining 47 records (table 49) were read directly from the film accelerograms. In addition to these data, table 49 lists the stations that recorded the aftershocks and the peak accelerations recorded for each aftershock. These peak accelerations, obtained from the maximum trace amplitudes, have not been corrected for the response of the accelerometers. Figure 297 illustrates the spatial relation between the preliminary aftershock locations and the accelerographs that recorded them. About 75 percent of the triggerings occurred on the three northernmost accelerographs (stations 3689, 3692, 3698, fig. 296); the two southernmost stations (3695, 3696) did not record any aftershocks. This pattern is consistent with the distribution of the aftershock sequence, in which most of the later aftershocks occurred north of Brawley, Calif. (Johnson and Hutton, this volume).

TABLE 48.—*Temporary accelerograph sites*

[Location is within ±0.003°. Sensor orientation is direction of ground motion that causes positive trace motion on the film; upward ground acceleration causes positive trace motion on the vertical component. Accelerograph characteristics were supplied by Kinemetrics; damping is 60 percent of critical on all instruments]

Site	Station	Location		Elevation (ft)	Sensor orientation (azimuth)		Accelerograph characteristics		
		Latitude N.	Longitude W.		Longitudinal	Transverse	Axis	Sensitivity (mm/g)	Natural frequency (Hz)
Del Rio Country Club	3698	33.0095°	115.5207°	−145	081°	351°	Long.	18.9	25.8
							Vert.	18.8	25.6
							Trans.	18.3	25.7
Brawley Airport	3689	32.9914°	115.5167°	−130	250°	160°	Long.	18.7	25.0
							Vert.	18.6	24.8
							Trans.	19.0	24.9
Sam Etchegaray Livestock Co.	3692	32.9816°	115.4743°	−135	338°	248°	Long.	18.5	24.5
							Vert.	18.5	25.5
							Trans.	17.4	26.4
Doyle McDuffy home	3681	32.9133°	115.4920°	−132	334°	244°	Long.	19.7	24.2
							Vert.	18.2	25.7
							Trans.	17.5	26.3
Memory Gardens Cemetery	3693	32.8919°	115.5676°	−80	095°	005°	Long.	19.6	24.2
							Vert.	18.0	25.6
							Trans.	19.3	24.7
Sharon Fox home	3678	32.8437°	115.4996°	−100	357°	267°	Long.	18.1	26.1
							Vert.	19.4	25.6
							Trans.	18.3	25.8
University of California Field Station	3697	32.8044°	115.4467°	−55	000°	270°	Long.	18.9	24.9
							Vert.	19.4	25.2
							Trans.	17.6	26.0
McGrew Farm	3688	32.7769°	115.4448°	−25	356°	266°	Long.	19.5	24.3
							Vert.	17.6	25.8
							Trans.	17.0	27.2
Jasper Road	3695	32.7090°	115.4244°	15	180°	090°	Long.	18.1	26.3
							Vert.	18.7	25.3
							Trans.	19.3	25.2
Tuttle Ranch	3696	32.6940°	115.3745°	25	100°	010°	Long.	17.8	26.2
							Vert.	18.2	25.4
							Trans.	17.1	26.9

Station 3698 did not record any events between 4:16 p.m. P.d.t. October 16 and 1:33 p.m. the next day because the film jammed. The vertical component of the station 3692 instrument was knocked badly out of alinement on the trip to the Imperial Valley or during installation and, therefore, did not record any data. Stations 3688, 3693, 3695, and 3696 were not on battery chargers, and the batteries were drained when those instruments were recovered on November 2.

The largest aftershock recorded was an $M_L = 4.9$ event that occurred at 4:16 p.m. P.d.t. October 16; this aftershock triggered the eight northernmost accelerographs. The preliminary epicentral location is 7½ km north-northwest of station 3698, at a depth of 5 km. This event is characterized by strong relatively long period accelerations on the horizontal components of the three northernmost stations, and by high-frequency shaking on the vertical components. At stations 3689 and 3698, near-field effects are clearly visible on the horizontal components before the arrival of the *S* wave (fig. 298). These records may be useful for studies of wave propagation and attenuation along the fault zone.

Several accelerograms in figure 298 have been digitized on the automatic digitizer at the University of Southern California and integrated according to the accelerogram-processing techniques of Trifunac and Lee (1973). Figure 299 shows the results for the three northernmost stations. This processing is not optimal for all these records because long-period ringing from the filter may be present on some processed displacement traces, and nearfield permanent displacements are removed by the baseline correction. The peak accelerations on these digitized and processed records are smaller than those listed in table 49 for all stations, and for the vertical component at station 3689 the reduction is large—from 0.63 to 0.26 g. This effect, which has been

noticed before (California Institute of Technology, 1976), results from sampling the data at too large a time interval to define the high-frequency peaks adequately. The solitary large peak on the station 3689 record (fig. 298) has a duration of 0.03 s between adjacent zero crossings and was sampled at 0.02-s intervals, and so it is not surprising that the digitized peak is greatly reduced.

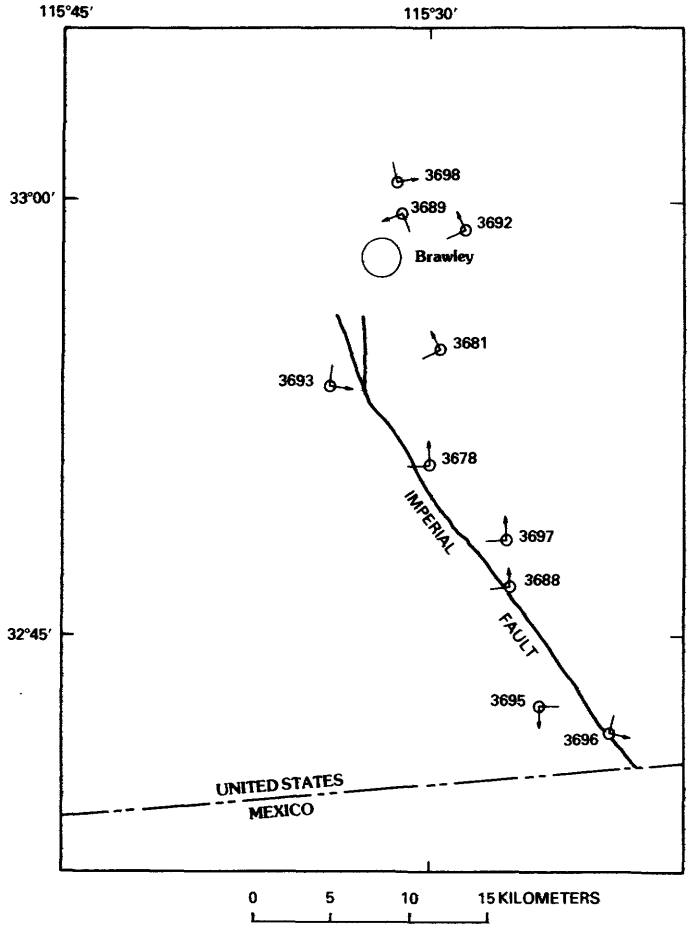


FIGURE 296.—Locations of temporary strong-motion accelerometer stations (see table 48). Arrows show direction of ground acceleration that causes positive amplitudes of recorded motion on longitudinal component of accelerometer; lines without arrows denote direction of positive motion on transverse component. Location of Imperial fault after Strand (1962).

Horizontal velocities and displacements on these records have relatively simple S-wave pulses that probably are dominantly controlled by the physics of the source for this particular aftershock.

ACKNOWLEDGMENTS

Several persons and institutions readily cooperated to help install the accelerographs quickly after the earthquake. These included A. Amini and B. Westermo of the University of Southern California, D. Helmberger of the California Institute of Technology, D. Halverson of Kinemetrics, Inc., and D. Hadley of Sierra Geophysics. Without their prompt response, this project would not have been possible. We also thank the following persons and institutes for allowing us to install an accelerograph on their property: Del Rio Country Club, Brawley Airport, Sam Etchegaray Livestock Co., the University of California Field Station, D. McDuffy, S. Fox, E. McGrew, and the California Institute of Technology. V. W. Lee, M. D. Trifunac, and M. Dravinski helped to digitize and process the accelerograms. The Los Angeles accelerograph network is supported by National Science Foundation Grant PFR 78–06926.

REFERENCES CITED

California Institute of Technology, 1976, Strong-motion earthquake accelerograms index volume: Pasadena, California Institute of Technology, Earthquake Engineering Research Laboratory Report EERL 76–02, 42 p.

Kinemetrics, Inc., 1977, Operating instructions for the time code generator, TCG–1: Pasadena, Calif., 14 p.

Strand, R. G., compiler, 1962, San Diego-El Centro sheet *of* Geologic map of California: California Division of Mines and Geology, scale 1:250,000.

Trifunac, M. D., and Lee, V. W., 1973, Routine computer processing of strong-motion accelerograms: Pasadena, California Institute of Technology, Earthquake Engineering Research Laboratory Report EERL 73–03, 360 p.

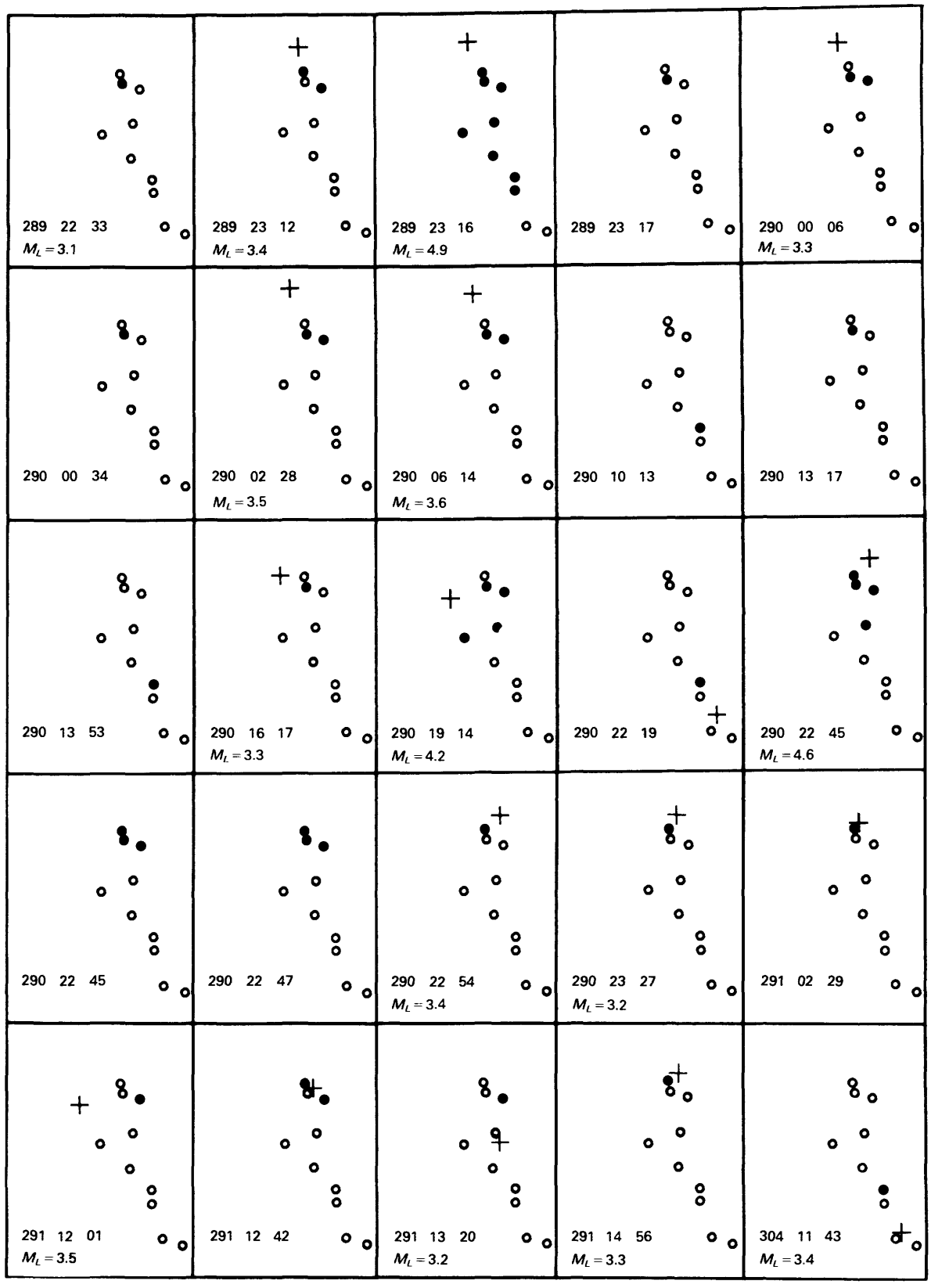


FIGURE 297.—Summary of strong-motion data recorded at temporary accelerometer stations (see table 49). Each frame is a simplified map representing one aftershock. Stations (see fig. 296 for locations) are shown as either circles (no record) or dots (record), and preliminary epicentral locations, where available, as crosses. Julian day, hour, and minute (G.m.t.) of aftershock is given in lower left corner, and preliminary local-magnitude estimates are given for events of $M_L \geq 3$.

TABLE 49.—*Summary of aftershock accelerograms*

[Time of event is Julian day (Jan 1=1, Oct. 15=289) and Greenwich mean (G.m.t.); for Pacific time, subtract 8 hours (P.s.t.) or 7 hours (P.d.t.). Locations were determined without use of *S*-wave arrival times listed for these accelerometers. Depth measurements are particularly unreliable (C. E. Johnson, oral commun., 1979). See table 48 for azimuthal directions of horizontal components of peak accelerations]

Event					Location (lat, long)	Depth (km)	Magnitude	Station	Preliminary epicentral distance (km)	Peak accelerations (*g*)		
Day	Hr	Min	Second									
			Trigger	*S* arrival						Longitudinal	Vertical	Transverse
289	22	33	59.53	61.50	----	----	3.1	3689	----	0.02	0.03	0.02
289	23	12	38.36	39.19	33°4.32′ N.,	1.8	3.4	3698	7.0	.05	.03	.02
			38.46	40.75	115°31.94′ W.			3692	11.5	.03	----	.06
289	23	16	33.16	34.46	33°4.48′ N.,	5.0	4.9	3698	7.8	.30	.26	.16
			34.21	34.94	115°33.26′ W.			3689	10.0	.29	.63	.22
			33.71	36.22				3692	12.8	.41	----	.29
			35.68	38.14				3681	19.0	.06	.04	.05
			36.07	39.32				3693	20.3	.10	.03	.12
			36.92	40.63				3678	26.0	.09	.04	.07
			40.84	42.47				3697	32.0	.08	.01	.05
			44.74	(1)				3688	35.0	.04	.02	.02
289	23	17	29.81	31.49	----	----	----	3689	----	.09	.05	.02
290	00	06	23.70	25.44	33°3.80′ N.,	6.3	3.3	3689	8.8	.04	.06	.03
			24.26	26.56	115°32.75′ W.			3692	11.3	.07	----	.09
290	00	34	6.41	8.46	----	----	----	3689	----	.02	.04	.02
290	02	28	20.44	22.24	33°4.77′ N.,	5.0	3.5	3689	10.3	.05	.07	.08
			20.92	23.35	115°33.16′ W.			3692	13.0	.05	----	.03
290	06	14	3.87	5.60	33°4.31′ N.,	5.6	3.6	3689	9.8	.06	.05	.05
			4.31	6.61	115°33.04′ W.			3692	12.8	.08	----	.07
290	10	13	19.27	12.37	----	----	----	3697	----	.11	.06	.11
290	13	17	20.56	22.68	----	----	----	3689	----	.03	.01	.02
290	13	53	47.31	50.04	----	----	----	3697	----	.02	.02	.02
290	16	17	39.02	41.07	33°1.13′ N.,	6.2	3.3	3689	5.8	.02	.01	.02
					115°34.26′ W.							
290	19	14	41.41	44.08	33°58.32′ N.,	4.7	4.2	3689	8.5	.10	.02	.05
			41.62	44.91	115°36.36′ W.			3692	12.5	.05	----	.05
			40.91	43.65				3681	12.5	.06	.05	.06
			40.09	42.03				3693	9.8	.25	.08	.39
290	22	19	47.60	50.67	32°44.47′ N.,	17.8	----	3697	7.5	.02	.02	.02
					115°24.83′ W.							
290	22	45	35.14	36.37	33°2.73′ N.,	3.9	4.6	3698	5.0	.11	.15	.09
			35.41	37.18	115°29.40′ W.			3689	6.8	.21	.22	.13
			35.66	38.06				3692	7.3	.16	----	.18
			39.71	40.41				3681	14.8	.03	.02	.03
290	22	45	56.44	57.60	----	----	----	3698	----	.05	.03	.05
			56.46	58.22				3689	----	.12	.15	.10
			57.03	59.23				3692	----	.10	----	.09
290	22	47	7.86	9.16	----	----	----	3698	----	.03	.04	.03
			8.50	9.95				3689	----	.05	.04	.04
			8.88	10.66				3692	----	.04	----	.05
290	22	54	21.80	23.13	33°2.58′ N.,	4.8	3.4	3698	4.5	.01	.02	.02
					115°29.39′ W.							
290	23	27	32.82	33.80	33°2.52′ N.,	7.1	3.2	3698	4.0	.03	.02	.02
					115°30.19′ W.							
291	02	29	14.45	15.72	33°1.21′ N.,	5.0	----	3698	1.3	.04	.04	.04
					115°31.08′ W.							
291	12	01	15.17	16.33	32°58.25′ N.,	15.3	3.5	3692	13.5	.02	----	.01
					115°36.99′ W.							
291	12	42	24.78	25.90	33°0.40′ N.,	5.1	----	3698	2.5	.02	.03	.01
			25.22	27.34	115°29.75′ W.			3692	3.5	.09	----	.13
291	13	20	29.81	32.89	32°54.17′ N.,	5.0	3.2	3692	9.0	.02	----	.02
					115°29.48′ W.							
291	14	56	21.04	22.37	33°2.19′ N.,	5.1	3.3	3698	4.3	.03	.03	.03
					115°29.59′ W.							
304	11	43	49.66	52.78	32°43.35′ N.,	17.4	3.4	3697	9.5	.03	.04	.06
					115°24.80′ W.							
For the following events, the clocks did not work properly:												
291	02	29?	----	----	----	----	----	3689	----	.09	.04	.05
or	12	01?										
291	12	42?	----	----	----	----	----	3689	----	.09	.05	.07
291	13	20?	----	----	----	----	----	3689	----	.03	.03	.02
or	14	56?										
		?	----	----	----	----	----	3678	----	.04	.02	.04
		?	----	----	----	----	----	3678	----	.03	.03	.04

[1]Triggered during *S*-wave arrival.

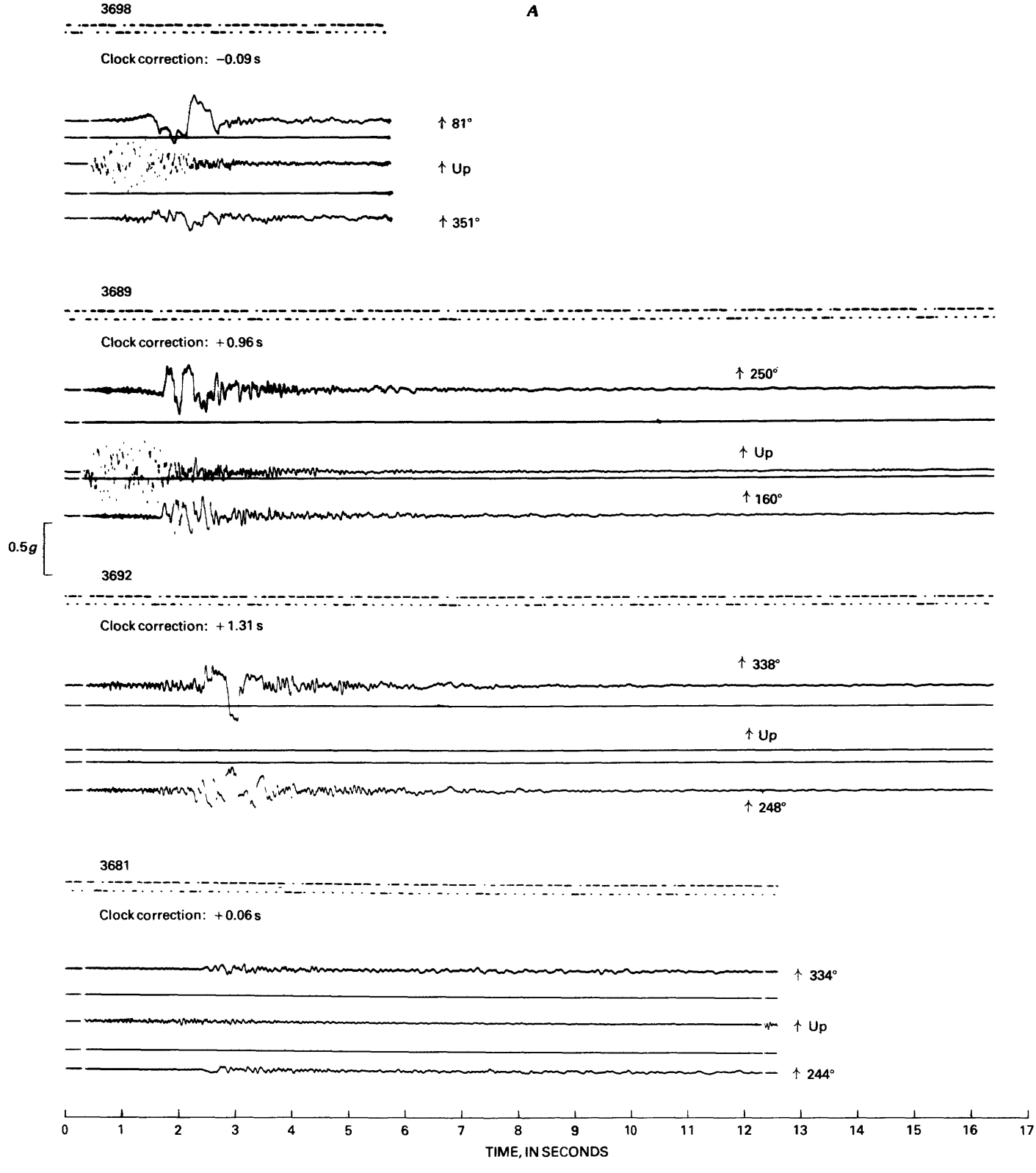
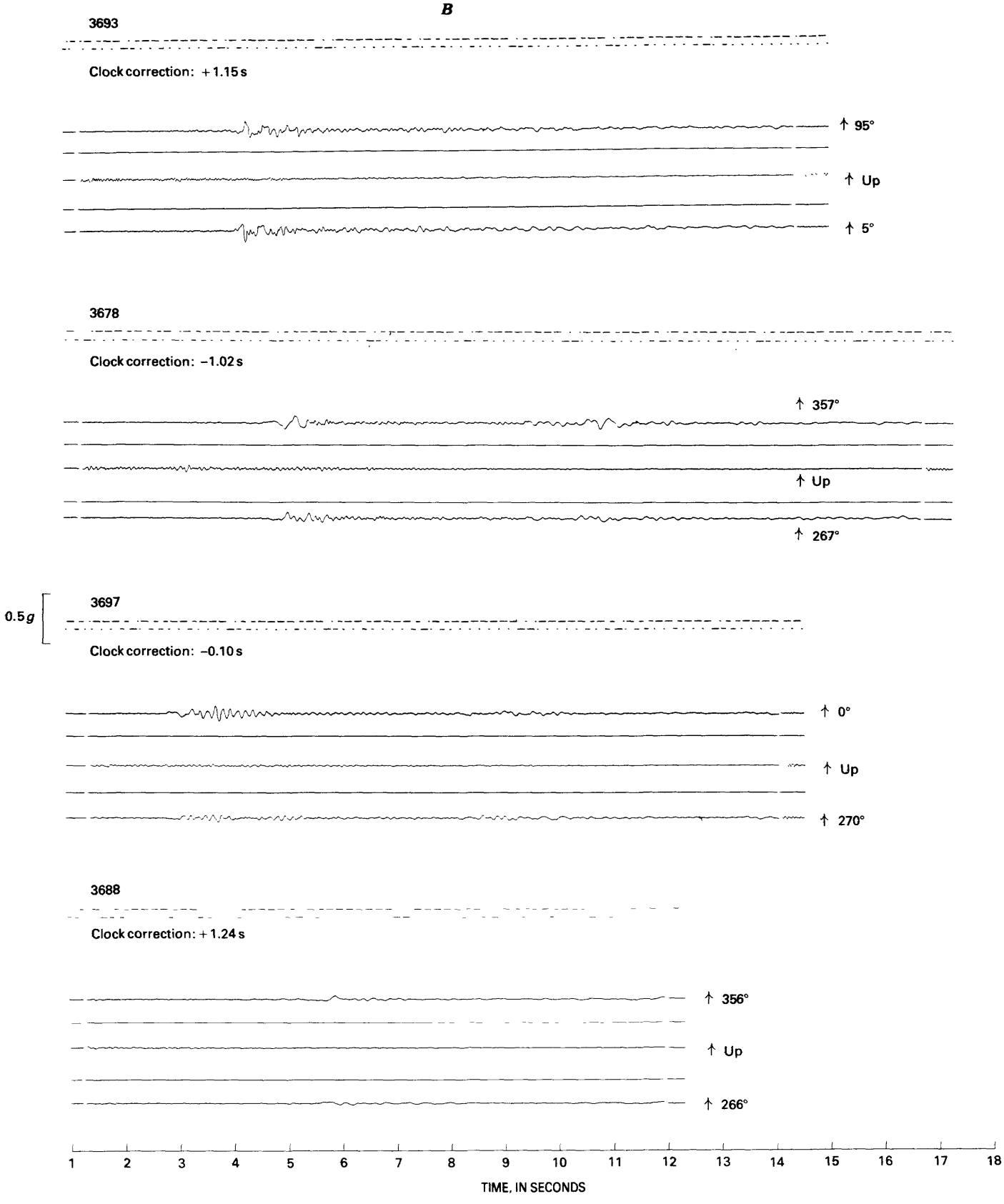


FIGURE 298.—Original accelerograms from $M_L = 4.9$ aftershock of October 16, 1979. Records are shown from north (top) to south (bottom) in order of increasing epicentral distance. Time trace at tip of each record gives a code with 5 (downward) pulses per second; code is interpreted as in Kinemetrics, Inc. (1977). Clock corrections at time of aftershock are also shown. Numbers to right on each trace indicate longitudinal, vertical, and transverse azimuths from top to bottom, respectively. *A*, Northern four records. *B*, Southern four records.



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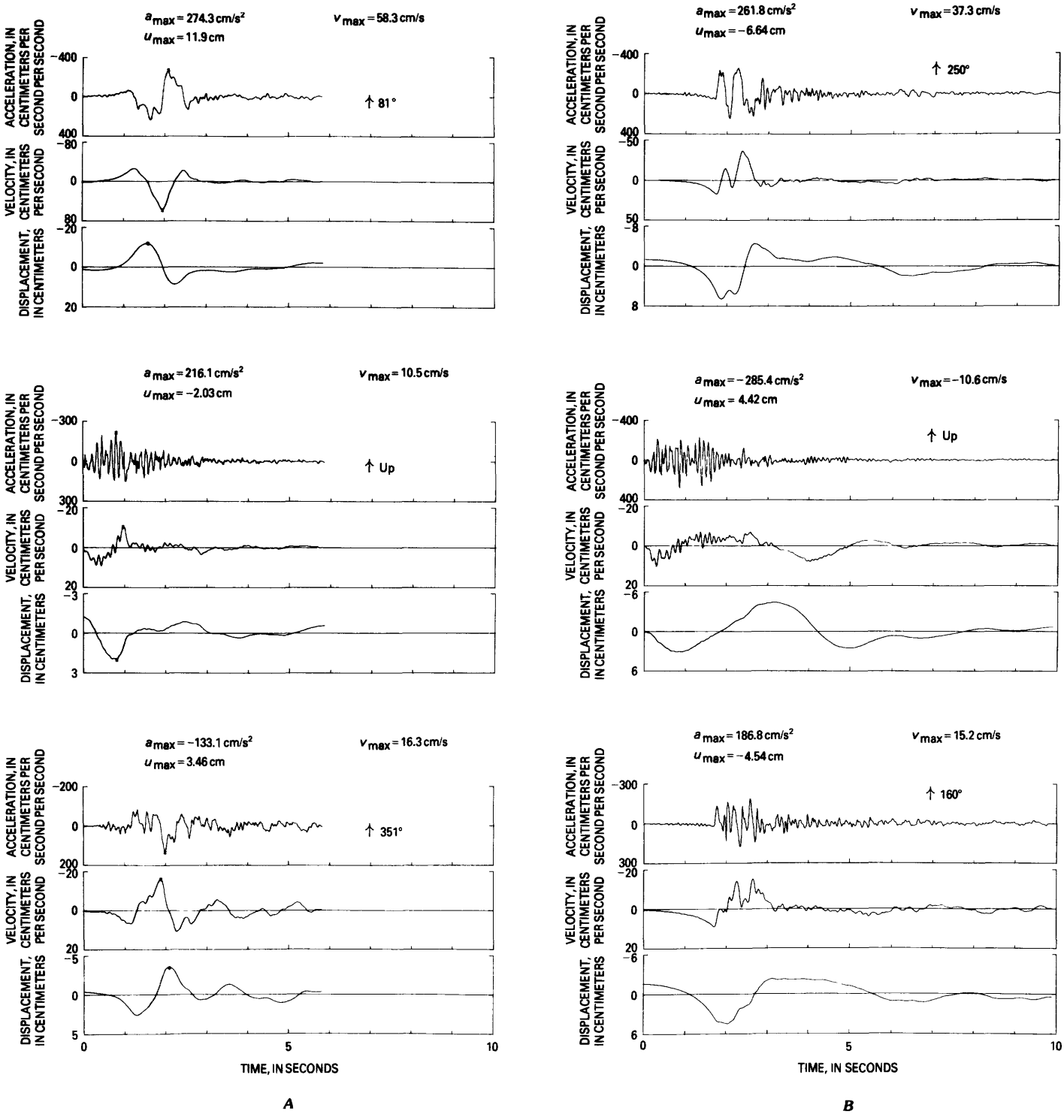
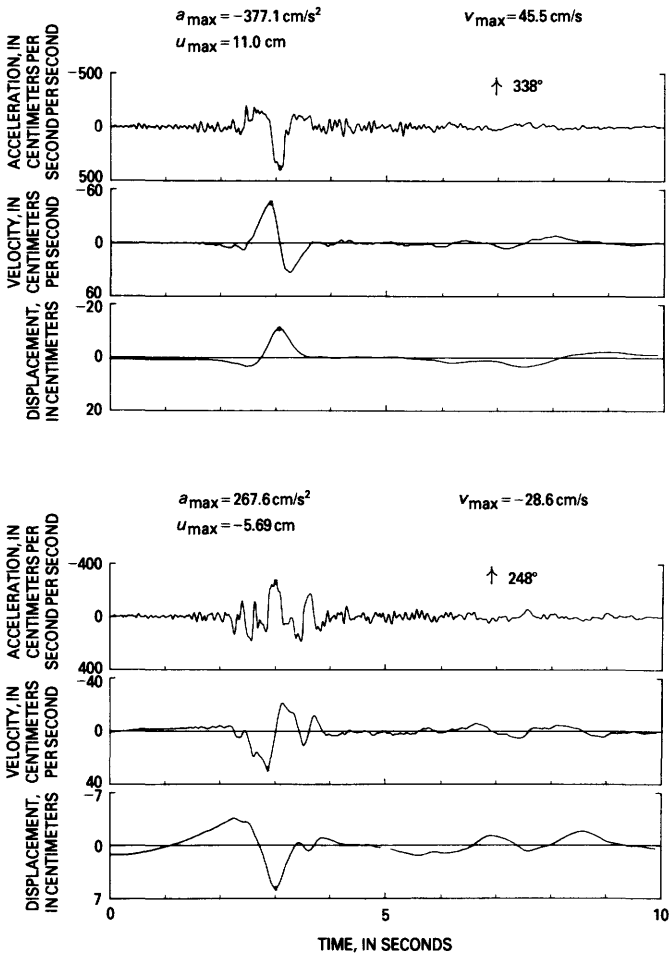


FIGURE 299.—Digitized, baseline-corrected, and integrated accelerograms from three stations closest to epicenter of M_L=4.9 aftershock of October 16, 1979: 3698 (*A*), 3689 (*B*), and 3692 (*C*). Only first 10 s of digitized record is shown; numbers to right on each graph indicate longitudinal, vertical, and transverse azimuths from top to bottom, respectively. a_{max}, maximum acceleration; u_{max}, maximum displacement; v_{max}, maximum velocity.



C

FIGURE 299.—Continued